



Load sensors for the LHC Low Beta Quadrupoles – design and validation –

Introduction

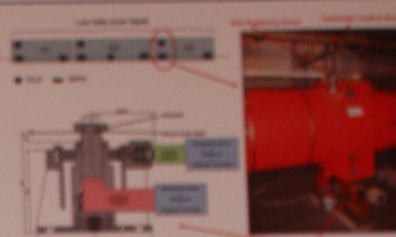
The superconducting low beta quadrupoles of the Large Hadron Collider (LHC) provide the final focus for the four main experiments in the LHC (ATLAS, CMS, ALICE and LHCb). Each side of experiment is equipped with three of these magnets (Q1, Q2, Q3), called *Inner triplet*. The position of each individual quadrupole is determined in five degrees of freedom, with a combination of two monitoring systems: The Wire Position System (WPS) and the Hydrostatic Leveling System (HLS).

When the deviations with respect to a reference position becomes greater than a given threshold, it is possible to move each cryostat to this reference position using the motorized jacks.

Reliable displacement – A problem of contact between jack and cryostat

During repositioning, the contact between the cryostat and the head of one jack can be lost, as experienced during repositioning in 2011. This could be the cause of disastrous damages to the magnets at the level of the interconnections between the magnets.

As solution to this problem it was proposed to install load sensors between cryostats and jacks in order to control the applied load at each contact point.



Requirements

Sensors

- 80 radiation-hard sensors will have to be installed, one for each jack
- Radiation level in the low beta quadrupoles areas is expected to be ~ 16 kGy/year
- Compact dimensions needed – maximum $\phi=70$ mm and a $h=16,5$ mm
- Resolution of about 100 N to 300 N and precision of about 500 N to 1000 N is sufficient
- Long term sensor stability needed
- Installation of the sensors should be plug-and-play



Electronics

- Tiny integration with existing control system
- Conditioners shall be able to work with long sensor cables, which can be up to 270 m, within the noisy environment

Studied solutions

Off the shelf: strain gauge washer type sensor + conditioner

The HBM KMR100 sensor and conditioner HBM AE301 Sensor and conditioner are manufactured by HBM company.

This washer type sensor has compact dimensions which allow an easy integration into the jack. Radiation-hard sensor version was possible to be designed.



Off the shelf strain gauge washer type sensor + home made conditioner

On the basis of the cost reduction requirement, the HBM KMR100 washer sensor was tested with the home made conditioner to compare performance of the sensor-cable-conditioner configuration with respect to industrial solution.

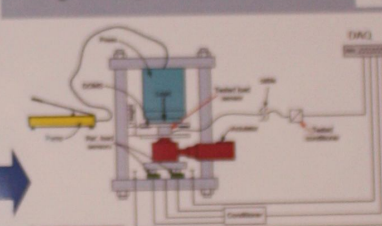
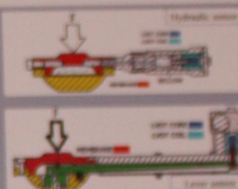


Test facility

To carry out performance tests of the different combinations of load sensors and conditioners a special test bench was designed and manufactured. The test bench allowed measuring different parameters as the conditioner's output signal and deformation as a function of the applied load and the ambient temperature.

LVD based sensors

Two types of home-made Linear Variable Differential Transformer (LVDT) based membrane sensors and one special electronic conditioner were developed. The advantage of these solutions was the reduction of cabling costs whilst keeping measurement accuracy for long cable lengths.



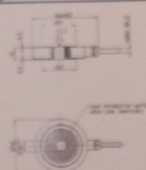
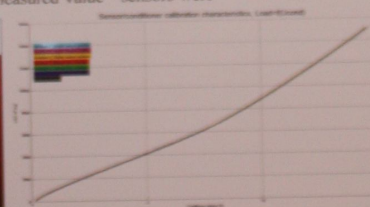
Solution selected and final results

Sensor

The strain gauge, washer type solution was selected as it offered the best performance. Based on preliminary test results for the industrial KMR100 sensor, it was decided to order HBM MPZ1108010, radiation-hard force washer sensors with an operating range: 0 kN to 200 kN, specially designed for CERN specifications.

To achieve needed sensor accuracy and obtain better repeatability, the MPZ sensors were embedded between interface hardened washers. According to sensor nonlinear characteristic and the impact of long signal cables for measured value - sensors were in-situ calibrated.

Final sensor accuracy was achieved at the level of 0.5 kN to 1 kN in the 0 kN to 8 kN sensor range. Above 8 kN accuracy decreased to ~ 3 kN.



Signal conditioning

The home-made conditioner solution, as offering the performance similar to industrial AE301 conditioner and well suited for the application was selected. In consequence a 12 input channel acquisition crate, named Load Sensors Acquisition System (LSAS), was designed.



A noise robust and radiation-hard cable was needed; the solution was provided with the three pair double shielded MBB6 DRAKA cable; the type of cable that has been chosen at the beginning for all force washer tests presented previously.

Tested with cables length of 270 m and the MPZ sensor connected, the noise of the LSAS crate, single channel output signal was at the level of 50 N with a resolution of 30 N.

Conclusions

Currently 7 out of 24 cryostats are equipped with 23 sensors. The analysis of the measurement data showed high stability of sensors signal also during the operation of the LHC. Within the first two months of operation in constant conditions, the sensors do not show signal drift (creeping) greater than 200 N whilst being loaded at 25% of nominal force. The output signal noise increased to approximately 200 N for some cables. This can be linked to the use of industrial cable paths that are shared with other users and therefore create a noisy environment.